Effect of Processing Conditions on the Viscosity of Tomato Juice[a]

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Under conditions comparable to commercial operations, the factors affecting the consistency of tomato juice were studied. It was demonstrated that a wide range of viscosities can be obtained by adjusting finishing conditions at a given preheating temperature. The finisher was shown to be an important unit in controlling viscosity. The effect of the preheater on gross viscosity is due to a softening of the chopped tomatoes prior to finishing in addition to the preservation of the pectin in the serum. Microscopic study indicated gross viscosity to be due primarily to the number and shape of suspended particles. A difference of 20% in gross viscosity is perceptible to a taste panel.

During the preliminary phase of a study on the relationship of raw product grades to the quality of canned tomato juice *(1)*, large variations were noted in the viscosity of juice prepared on a pilot plant scale. This prompted a study of the factors affecting tomato juice consistency under conditions comparable to commercial operations.

Kertesz and co-workers *(2, 3, 5)* have pointed out that the viscosity of whole tomato juice (gross viscosity) depends upon the viscosity of the serum (tomato juice freed of suspended particles) and upon the viscous character of the suspended particles. The role of pectin in determining viscosity and the importance of the preheating temperature for inactivation of the pectic enzymes were emphasized. As a result of these laboratory studies and limited tests under commercial conditions *(7)*, a relatively high preheating temperature was recommended for the manufacture of tomato juice.

The results presented in this paper show that a wide range of viscosities can be obtained by adjusting the finishing conditions at any given preheating temperature. Since the maximum obtainable gross viscosity is not generally desired in commercial tomato juice, it is not necessary to preserve the pectin in the serum.

It should be pointed out that these results do not necessarily apply to tomato products in which maximum viscosities might be desirable.

EXPERIMENTAL

The processing equipment used in this study simulated commercial production of tomato juice in a continuous manner at the rate of 1 gallon per minute *(6)*. Because the individual units of this processing line were small, it was possible to interchange them and to vary the manufacturing conditions over a wide range. In addition to the paddle type finisher[c] normally used in the grade relationship study, a tapered screw type extractor[d] was employed on occasions to remove the skins and seeds. A small piston type homogenizer[e] was used when studying the effects of homogenization on juice viscosity.

A further advantage gained through the use of small scale equipment lay in the small lots of raw material needed for each experimental condition which made it possible to complete a series of tests with one load of tomatoes. Variation in quality of raw material was further reduced by segregating each load into grades, No. 1, No. 2A (color deficient) and No. 2B (defects), and then weighing definite amounts of each grade to form experimental lots of 125 to 150 pounds each.

Viscosity measurements were made on the whole tomato juice samples (gross viscosity) and upon the tomato juice serum after removal of the suspended solids by filtration. Since tomato juice is a non-Newtonian liquid wherein stress is not proportional to rate of shear, all single gross viscosity measurements are actually "apparent viscosity" values as presented in this paper.

A wide range of manufacturing conditions in the pilot plant has produced juices with extreme variations in both serum and gross viscosity (Figure 1). The serum viscosities range approximately from 0.95 to 2.3 centipoises at 30° C., as measured in a 5-ml. Ostwald viscosity pipette. The apparent gross viscosities varied from 20 to 375 centipoises at 30° C., as measured with a Brookfield Model LVF viscosimeter using a No. 2 spindle at 60 r.p.m. Viscosity measurements in the Stormer viscosimeter, also at 30° C., were made using a 50-gram weight. In using the Brookfield viscosimeter, centipoise values are read directly. In the case of the Stormer, the centipoise values were obtained by preparing a curve with standard sugar solutions. At any given temperature the apparent viscosity of a truly viscous material never changes, but the apparent viscosity of all other types of material changes with variation of stirring speed. Since whole tomato juice is not a truly viscous material, the Broookfield viscosimeter, having a constant rate of revolution, is the preferable instrument.

The ranges in serum and gross viscosities encountered during the 1951 season are shown in Figure 1, with the range of the commercial samples emphasized by enclosure within the broken line.

In addition to theoretical considerations the Brookfield instrument was found to be preferable to the Stormer viscosimeter because of greater sensitivity in the region of viscosities found in commercial tomato juice and because of the speed and convenience in making the tests. The relation between measurements made by the two instruments is shown in Figure 2. In the region of extremely high viscosities, the range of the two instruments is in closer agreement, but in this region the Stormer is tedious to use because of difficulty in getting agreement between readings and because the observed viscosity of a given sample decreases with each repeated determination. Al-

[a] Approved by the Director of the New York State Agricultural Experiment Station for publication as Journal Paper No. 946.

[b] Deceased, February 17, 1955.

[c] F. H. Langsenkamp Co., Indianapolis, Indiana Catalog No. 48, p. 27.

[d] Chisholm-Ryder Co., Niagara Falls, New York Catalog No. 51, p. 54.

[e] Cherry-Burrell Corp., Chicago, Illinois Size Jr. 75.

though single measurements of the viscosity of a non-Newtonian fluid are of limited theoretical significance, it was decided, for practical purposes, to make use of the Brookfield viscosimeter in order to obtain readings related to consistency. In interpreting the data, it must be borne in mind that apparent viscosities of non-Newtonian materials such as tomato juice are not absolute values, but vary widely with the method of measurement.

Sensory Perception of Consistency

Numerous tests with taste panels have demonstrated that the average observer is sensitive to gross viscosity in tomato juice and can distinguish differences amounting to about 20%. Using the triple test method with one of 3 samples differing in gross viscosity by 25%, the taste panel was able to make a significant number of correct selections of like and unlike samples. Figure 3 shows a typical series of taste tests demonstrating the effect of decreasing gross viscosities on the percent of correct selection.

The taste panel was not nearly so sensitive to differences in serum viscosity in triple tests when all 3 samples had the same gross viscosity. One comparison was made involving an increase of almost 100% in serum viscosity (far outside the range of any commercial samples encountered in this investigation) with less than the significant percentage of correct selections. The detailed results of the experiments with the taste panel are given in Table 1.

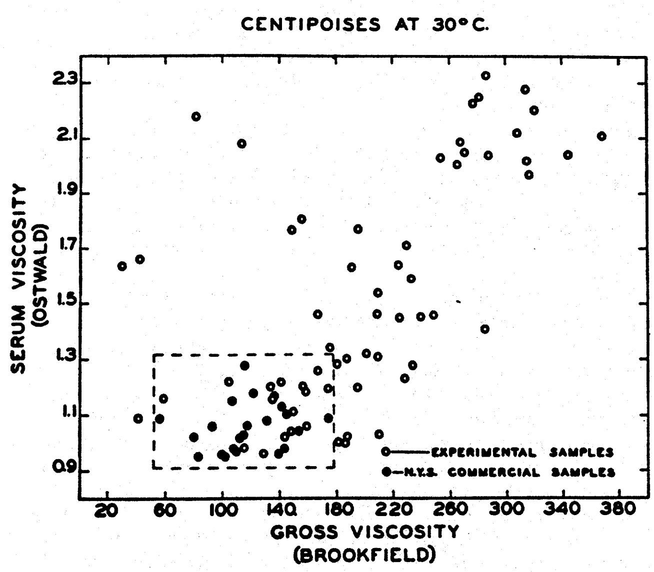


Figure 1. Range in serum and gross viscosities of tomato juice.

Great care needs to be taken in the interpretation of the taste panel results. A significant percentage of correct selection proves only that a detectable difference exists. The samples must be so selected that the difference is solely in viscosity and that the selection is not assisted by any other differences such as flavor, color, or coarseness of particles.

All of the samples used in the taste panel studies had been manufactured with the same finisher screen. Obviously differences in coarseness of particles will affect the sensation of smoothness which is an important ment of mouth feel or consistency. Smoothness is imparted to juice by the use of a fine screen at the finisher or by homogenizing. These experiments demonstrate that in juices with uniform gross viscosity and particle size, large differences in serum viscosity do not impart any detectable differences in consistency.

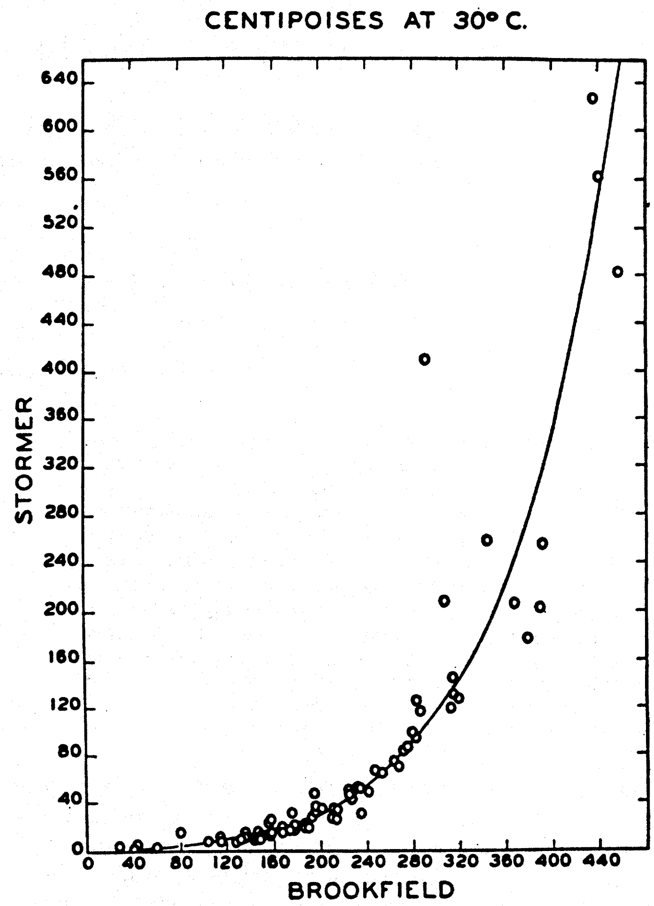


Figure 2. Brookfield and Stormer viscosities of tomato juice.

The Effect of Action of the Finisher on Gross Viscosity

In the range of conditions likely to be encountered in the manufacture of tomato juice, the preheating temperature primarily determines serum viscosity while the speed and type of finisher exerts its greatest effect on gross viscosity. The effects of processing conditions

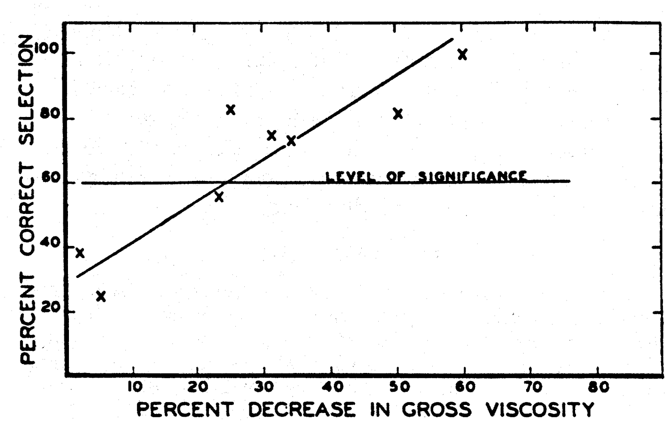


Figure 3. Taste panel tests on tomato juice viscosity. The relation of percent correct selection to decrease in gross viscosity.

TABLE 1
Taste panel tests on the viscosity of tomato juice

Viscosity in cp at 30° C.		% decrease in viscosity		Number of tasters	Percent correct selection	Percent correct selections needed		
Gross	Serum	Gross	Serum			Significant	Highly significant	Very highly significant
170 69	1.18 1.16	60	2	13	100	58	66	76
235 119	1.29 1.26	50	2	13	81	58	66	76
263 174	1.03 1.02	34	1	11	73	60	69	81
171 118	1.18 1.00	31	15	12	75	59	68	79
157 118	1.16 1.00	25	14	12	83	59	68	79
235 180	1.29 1.28	23	1	16	56	57	64	74
253 240	1.46 1.28	5	13	8	25	61	72	83
241 237	1.98 1.04	2	48	13	38	58	66	76
	1.98[1] 1.04[1]		48	10	30	61	79	83

[1] Serum of these juices separated by centrifuging.

on the serum and gross viscosities of tomato juice are shown in Figures 4 and 5 for two preheating temperatures and with and without preheating. Some effect on serum viscosity was produced by changes in finisher speed. However, this effect was small in comparison to the several-fold increase in gross viscosity.

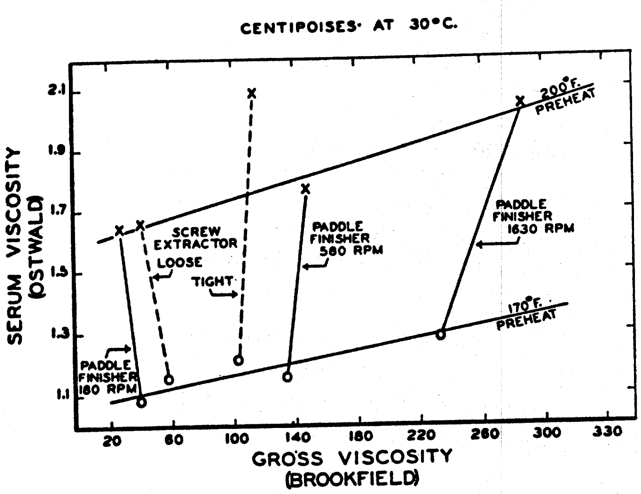


Figure 4. Effect of finisher on viscosity of tomato juice at two preheating temperatures.

Since gross viscosity was found to depend on finisher speed, the studies were extended to determine the effect of finisher speed over the entire range of preheating temperatures. Contrary to expectations it was found that juice that was relatively high in both serum and gross viscosity could be obtained at a finishing temperature of 70° F. without preheating. This fact is largely of theoretical significance since there are other reasons justifying the use of a preheater.

Figure 5 shows a comparison of the effects of finisher speed (paddle type) on both serum and gross viscosity of juice with and without preheating. It is apparent that the preheating temperature affects both serum and gross viscosity and that its effect on gross viscosity becomes more pronounced as the finisher speed is increased.

Depending upon the temperature reached and rate of heating, heat treatment prior to finishing may either stimulate or destroy pectic enzymes. In addition to its effect on serum pectin, the preheater exerts a softening effect on the tomato tissue which in turn has an important practical influence on the action of the finisher. In the usual continuous process of manufacture, preheating and finishing temperatures are approximately the same. In order to separate the effect of temperature at the preheating and finishing operations, tomato juice was cooled after preheating, and then heated a second time to the desired finishing temperature. Assuming that the first heat treatment inactivated the pectic

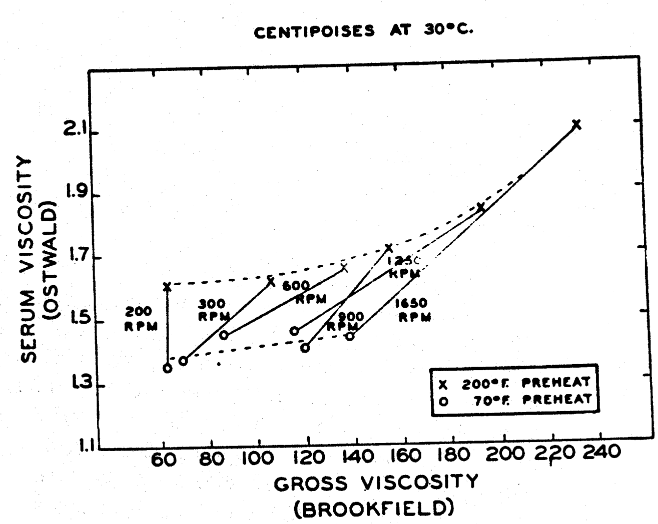


Figure 5. Effect of finisher paddle speed on viscosity of tomato juice with and without preheating.

enzymes, it can be concluded that the second heat treatment altered both serum and gross viscosities by further softening of the tomato tissue prior to finishing (Table 2). These results also show the direct interrelationship between serum and gross viscosities.

TABLE 2

The effect of finishing temperature on the viscosity of tomato juice

Preheating temperature	Finishing temperature	Viscosity of juice in cp at 30° C. Gross (Brookfield)	Serum (Ostwald)
° F.	° F.		
170	100	186	1.00
170	140	181	1.00
170	170	187	1.02
170	200	210	1.03
200	100	230	1.71
200	140	315	2.02
200	170	316	1.96
200	200	344	2.04

Instead of using the terms "hot and cold break" it is sufficient to state whether the chopped tomatoes were preheated prior to finishing and to report the preheating temperature. The use of the term "hot-break" has caused a great deal of confusion because of the implication that the necessary heating must be accomplished during or immediately after chopping or crushing in order to preserve the pectin in the juice *(3)*. As a matter of fact, holding chopped tomatoes at room temperature for several hours before heating causes no significant reduction in either serum or gross viscosity. Table 3 shows the results of experiments in which chopped tomatoes were held at 70° F. and at 130° F. for times up to 4¾ hours after chopping and before preheating. There was no significant effect on the viscosity of the juice except when the juice was finished without preheating and held for one hour after finishing. The explanation for the apparent discrepancy between these findings and earlier reports of the rapid disappearance of pectin *(3)* may be due to the fact that in the earlier work the cellular tissue of the tomatoes was more completely disrupted than would have occurred if a chopper had been used.

TABLE 3

The effect of holding chopped tomatoes on the viscosity of tomato juice

Conditions of holding after chopping: Temperature	Time hrs.	Finishing temperature	Viscosity of juice in cp at 30° C. Gross (Brookfield)	Serum (Ostwald)
° F.		° F.		
70	0	170	205	1.23
130	0	170	208	1.29
130	1	170	248	1.53
130	2	170	252	1.40
130	4	170	235	1.38
130	0	200	221	1.33
130	4	200	241	1.44
70	1¾	170	235	1.20
70	4¾	170	225	1.60
Conditions of holding after finishing				
70	0	70	209	1.77
100	1	70	174	.98

Table 4 is a summary of experiments conducted during the 1952 season showing the wide range in gross viscosities that can be obtained by a variation in processing conditions. The results appeared to depend to some extent on the degree of ripeness or condition of the tomatoes but repeated trials with identical manufacturing conditions showed remarkably close agreement.

TABLE 4

Effect of processing conditions on gross viscosity of tomato juice[1]

Finisher speed r.p.m.	Finisher screen size inches	Preheating temperature: 70° F. Gross viscosity cp	160° F. Gross viscosity cp	200° F. Gross viscosity cp
200	.023	46	14	27
200	.023	58	43	33
200	.033	77	59	53
200	.045	71	72	77
200	.060	92	80	97
400	.023	92	72	87
800	.023	120	138	127
800	.023	119	143	170
800	.033	150	160	211
800	.045	158	184	245
800	.060	192	178	259
1600	.023	138	117	176
1600	.023	141	168	206
1600	.033	157	197	246
1600	.045	155	201	257
1600	.060	183	224	272

[1] 1952—Red Jacket Tomatoes, No Vibratory Screen, Langsenkamp Paddle Finisher.

The observed increase in gross viscosity with increase in screen size is of no practical significance since the tomato juice made with all screen sizes above 0.023 showed defects due to the appearance of specks consisting chiefly of seed fragments.

The Effect of Preheating Temperature on Serum and Gross Viscosity

The effect of preheating temperature on serum and gross viscosities of tomato juice is shown in Figures 6

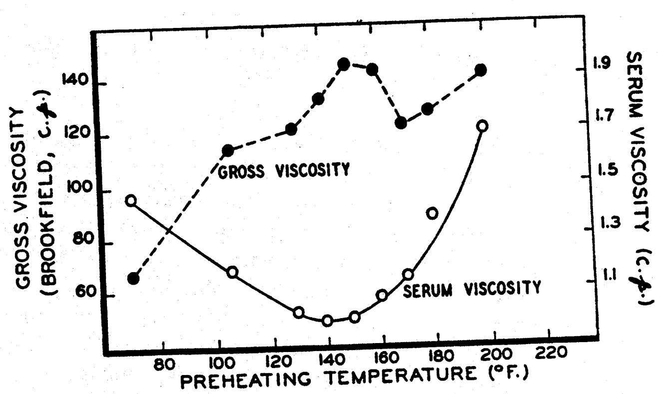


Figure 6. Effect of preheating on tomato juice viscosity with shaker screen and a paddle speed of 540 r.p.m.

and 7. With a slow finisher speed the gross viscosity was low at the low end of the preheating temperature scale. With the high finisher speed the gross viscosities were high at the higher preheating temperatures. At intermediate temperatures there was no constant trend.

The effect of preheating temperature on serum viscosity is much more clear-cut. The serum viscosity passes through a minimum at 140-150° F. On one side of this minimum the pectic enzymes are inactivated by the high temperature and on the other side of the minimum the enzymes are inhibited by the low temperature. The results in Figures 6 and 7 confirm the published fact that an elevation of preheating temperature will increase the gross viscosity of tomato juice *(3, 7)*. The production of tomato juice with high serum viscosity at low preheating temperatures has not previously been reported. It is interesting that the preheating temperatures (150-160° F.) most commonly employed commercially in New York are near the minimum for serum viscosity.

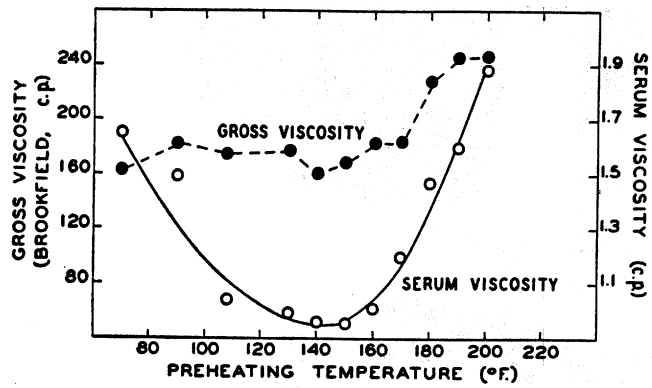


Figure 7. Effect of preheating on tomato juice viscosity without shaker screen and paddle speed 1600 r.p.m.

Manufacturing Conditions Other Than Finishing and Preheating

A number of studies have been undertaken to determine if other steps in the manufacturing process have a signicant influence on gross viscosity. The degree of chop was controlled by varying the slit width in the outlet below the chopper and was found to have little or no effect on the gross viscosity of the juice as shown in Table 5. This set of samples again illustrates the large effect of finisher speed on gross viscosity as well as a lesser effect on serum viscosity. Table 6 shows that the use of a vibratory screen in the pilot plant line *(6)* between the preheater and finisher has little or no effect on viscosity. Table 7 gives representative data demonstrating that the viscosity is independent of the pasteurization temperature.

TABLE 5
The effect of degree of chop on viscosity of tomato juice

Chopper slit width	Finisher speed r.p.m.	Viscosity in cp at 30° C. Gross (Brookfield)	Serum (Ostwald)
¼"	1630	294	1.98
½"	1630	298	2.22
¼"	580	160	1.71
½"	580	161	1.78

TABLE 6
The effect of a vibratory screen on the viscosity of tomato juice

Use of vibratory screen	Finisher operation	Viscosity of juice in cp at 30° C. Gross (Brookfield)	Serum (Ostwald)
Yes	1630 r.p.m.	221	1.12
No		252	1.21
Yes	580 r.p.m	196	1.10
No		193	1.12
Yes	screw	185	1.13
No	extractor	187	1.19

TABLE 7
The effect of pasteurizing temperature on the viscosity of tomato juice

Pasteurizing temperature	Viscosity of juice in cp at 30° C. Gross (Brookfield)	Serum (Ostwald)
200° F.	203	1.12
250° F.	195	1.20
265° F.	204	1.22

MICROSCOPIC EXAMINATION OF TOMATO JUICE PARTICLES

Data in previous sections of this paper indicated that it might be profitable to investigate microscopically the nature of the suspended particles in tomato juice. Unlike many other juices, tomato juice is made by comminution of whole fruit, except for skins and seeds. Thus the juice consists of entire plant cells and their constituent parts and is not merely the liquid or cell sap pressed from tissues. Juice characteristics might be expected to depend partly on the structure of the original cells and cell walls.

A fresh ripe tomato is composed chiefly of large, thin-walled, nearly spherical cells (Figure 8) that contain living matter, various granules, and aqueous sap. In a tomato the cells are loosely stuck together with a pectic

Photomicrographs of tomato cells and juices. Magnification of all samples was 20 ×. For Figures 8, 9, and 11, ordinary (non-polarized) illumination was used; polarized light was used for Figures 10, 12, and 13. Juices used for Figures 9, 10, 12, and 13 were diluted one-fold with water and photographed as a layer 350 microns thick.

Figure 8. Unstained, living flesh cells from the center of a tomato.

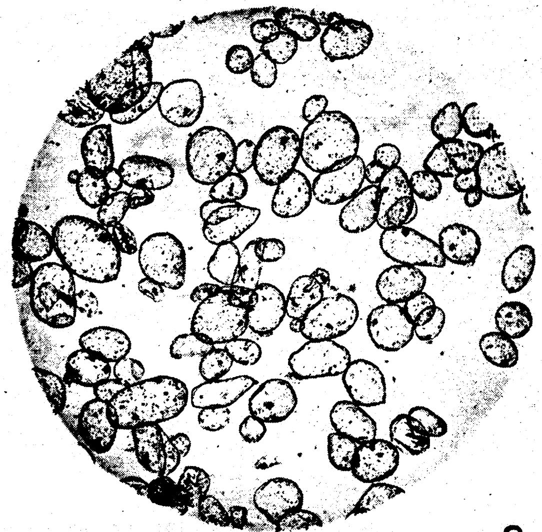
Figure 9. Tomato juice as it appears at low magnification under ordinary illumination. Most of the dark specks are color granules. Some of the cell walls may be seen faintly.

Figure 10. Juice similar to that used for Figure 9 under polarized light and crossed Polaroids. Cell walls are visible but granules and other non-birefringent structures cannot be seen.

Figure 11. Broken cells and cell clusters separated from a juice during sieve analysis. The structures passed a 20-mesh sieve but were retained on one of 40-mesh size.

Figure 12. Tomato juice containing a minimum of suspended solids. Its gross viscosity was exceedingly low.

Figure 13. Tomato juice containing an appreciable quantity of suspended solids. Its gross viscosity was high.



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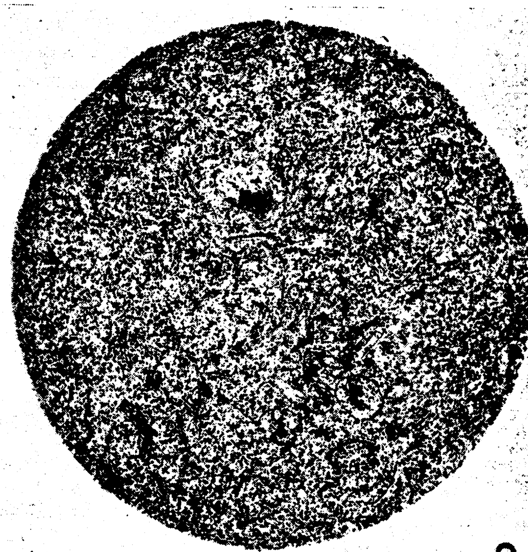

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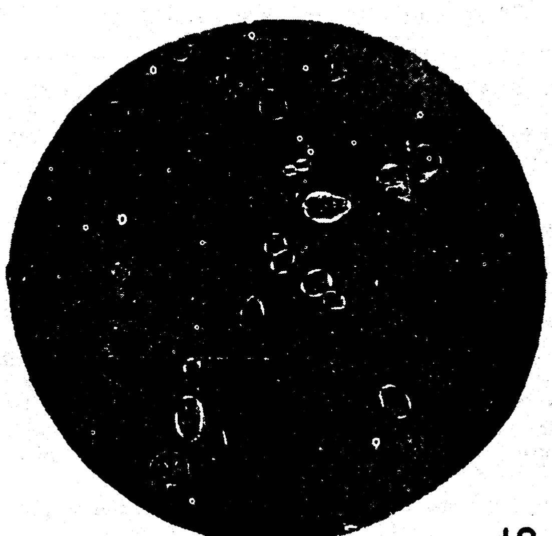

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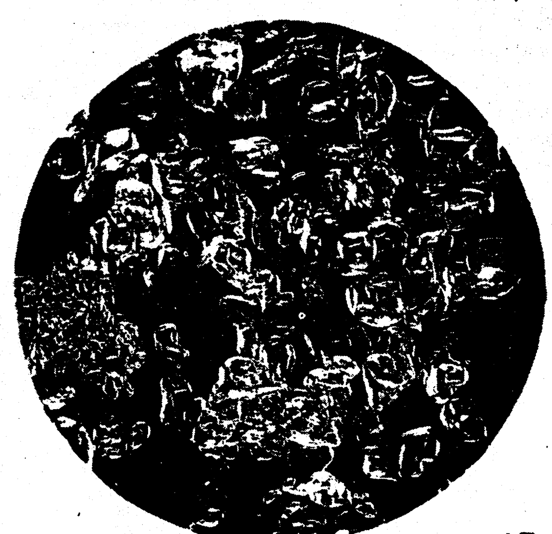

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PLATE 1

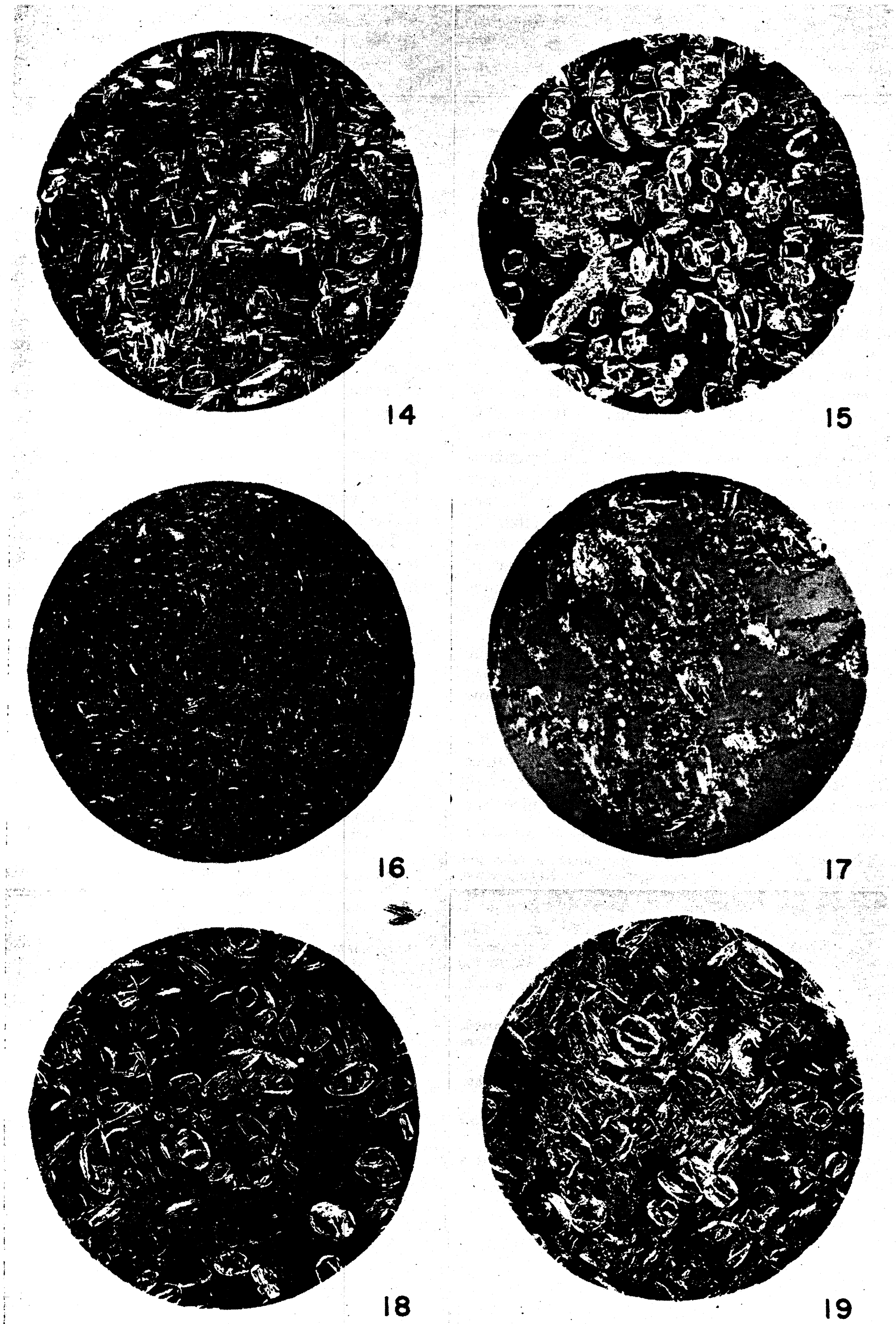

PLATE 2

cement. Although during juice manufacture the cells may become separated, distorted and broken, many of their structural parts are still recognizable in the finished juice. For instance, in Figure 9 the color granules liberated from broken cells are clearly visible, and in Figure 10, made with polarized light and crossed Polaroids, the cellulosic cell walls can be clearly seen. Cell walls may be seen faintly also in Figure 9, made under ordinary illumination. The structures shown in Figure 11 were obtained from a juice subjected to a sieve analysis as described by Kimball and Kertesz *(4)*. The relatively large cells, cell clusters, and cell wall fragments remaining on a 40-mesh sieve are seen.

If almost no suspended particles are present (Figure 12), the juice is extremely thin, its viscosity approximating that of water. If suspended matter is present in quantity (Figure 13), the gross viscosity of juice is high. However, quantity of cellular material alone may not govern gross viscosity; also important is the configuration or shape of the cell fragments. It is widely recognized that elongated particles have a greater effect on viscosity than do spherical particles. Thus fragmentation of the predominantly spherical cellular particles in a juice by partial homogenization (compare Figures 13 and 14) increases gross viscosity. The effect of more complete homogenization can be seen by comparing Figures 15 and 16. A higher magnification shows the brush-heap type of structure that contributes to the increase in viscosity caused by homogenization (see Figure 17).

The microscopic observations help to explain some of the results obtained by varying the conditions of finishing. For example, if the finisher is run at a low speed, a relatively small amount of suspended matter is incorporated in the juice, a high proportion of the particles remain spherical (Figure 18) and the juice is thin. At a high finisher speed, large quantities of suspended material are incorporated in the juice, the particles tend to be elongated (Figure 19), and the juice has a high gross viscosity. In most cases the significant differences in gross viscosity of juices can be explained in terms of differences in quantity, configuration, and character of the suspended particles. Work on the suspended cellular material in tomato juice is being continued.

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Photomicrographs of tomato juice. Magnification used for Figure 17 was 50 ×; for all other samples the magnification was 20 ×. All juices were diluted one-fold with water and photographed as a layer 350 microns thick in polarized light.

Figure 14. Suspended solids in a partially homogenized juice. Gross viscosity was very high. Suspended solids in the original juice before homogenization are shown in Figure 13.

Figure 15. Suspended solids in an unhomogenized sample of juice. Gross viscosity was moderately low.

Figure 16. Small particles in a juice completely homogenized. Gross viscosity was very high. The suspended solids before homogenization are shown in Figure 15.

Figure 17. The suspended solids as in Figure 16 at higher magnification.

Figure 18. The suspended solids in a juice prepared at a low finisher speed. Gross viscosity was low.

Figure 19. The suspended solids in a juice prepared at a higher finisher speed. Gross viscosity was high.

SUMMARY

Representative samples of New York State commercial tomato juice had serum viscosities ranging from 0.9 to 1.3 centipoises at 30° C. when measured in the Ostwald viscosimeter. The gross viscosity of the same samples ranged from 60 to 180 centipoises at 30° C. when measured with the Brookfield viscosimeter.

A difference of 20% in gross viscosity in two samples of tomato juice is perceptible to a taste panel. In samples of uniform gross viscosity a 100% difference in serum viscosity had no perceptible effect on consistency as determined by a panel.

The finisher is an important unit for controlling the gross viscosity of tomato juice. With a paddle-type finisher, adjustment of the speed of the paddle will provide a wide range of gross viscosity regardless of the preheating temperatures.

The effect of the preheater on gross viscosity is due to the softening of the chopped tomatoes prior to finishing in addition to the preservation of the pectin in the serum.

Microscopic examination of tomato juices indicates that gross viscosity is due primarily to the number and shape of the suspended particles.

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